The contribution of root respiration of *Pinus koraiensis* seedlings to total soil respiration under elevated CO_2 concentrations

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Abstract: The impacts of elevated atmospheric CO_2 concentrations (500 μmol·mol^{-1}and 700 μmol·mol^{-1}) on total soil respiration and the contribution of root respiration of *Pinus koraiensis* seedlings were investigated from May to October in 2003 at the Research Station of Changbai Mountain Forest Ecosystems, Chinese Academy of Sciences, Jilin Province, China. After four growing seasons in top-open chambers exposed to elevated CO_2, the total soil respiration and roots respiration of *Pinus koraiensis* seedlings were measured by a LI-6400-09 soil CO_2 flux chamber. Three PVC cylinders in each chamber were inserted about 30 cm into the soil instantaneously to terminate the supply of current photosynthates from the tree canopy to roots for separating the root respiration from total soil respiration. Soil respirations both inside and outside of the cylinders were measured on June 16, August 20 and October 8, respectively. The results indicated that: there was a marked diurnal change in air temperature and soil temperature at depth of 5 cm on June 16, the maximum of soil temperature at depth of 5 cm lagged behind that of air temperature, no differences in temperature between treatments were found (P>0.05). The total soil respiration and soil respiration with roots severed showed strong diurnal and seasonal patterns. There was marked difference in total soil respiration and soil respiration with roots severed between treatments (P<0.01); Mean total soil respiration and contribution of root under different treatments were 3.26, 4.78 and 1.47 μmol·m^{-2}·s^{-1}, 11.5%, 43.1% and 27.9% on June 16, August 20 and October 8, respectively.

Keywords: Contribution of root respiration; Elevated CO_2; *Pinus koraiensis*; Root-severed technique; Soil respiration
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Introduction

Soils are the major reservoir of carbon in terrestrial ecosystems, containing more than two-thirds of total carbon in the terrestrial part of the biosphere. A major unknown in the response to anticipated climate changes is the extent to which forest ecosystems will become net sinks or sources of CO_2. The regulation of net primary production is well known for most of the earth's ecosystem, however, our knowledge about underground respiration processes under elevated atmospheric CO_2 is quite poor (Raich & Potter, 1995). Understanding soil carbon dynamics under elevated atmospheric CO_2 and temperature is thus critical for predicting future regional and global carbon budgets (Schimel 1995). Previous studies have suggested that the increasing atmospheric CO_2 concentration and temperature can stimulate soil CO_2 efflux (van Veen *et al.* 1991; Körner & Arnone 1992; Peterjohn *et al.* 1993, 1994; Johnson *et al.* 1994; Nakayama *et al.* 1994; Pajari 1995; Vose *et al.* 1995; Hungate *et al.* 1997; Rey *et al.* 2001). However, there is relatively little information about which components of the soil CO_2 efflux are the most sensitive to the changes in atmospheric CO_2 (Paterson *et al.* 1997) or temperature.

Soil respiration includes three biological processes (soil microbes respiration, roots respiration and soil fauna respiration) and an abiotic process (oxidation of minerals containing carbon) (Singh & Gupta 1977). Roots are one of the major contributors to soil respiration. Field measurements are difficult because roots can not be extracted from the soil without any disturbance (Thierron and Laudelout 1996). Most of the direct measurements of roots respiration reported in the literature were performed with potted plants in a laboratory environment (Lambers *et al.* 1991). Hanson *et al.* (2000) reviewed and compared several methods for separating root and soil microbial contributions to soil respiration. Each approach has advantages and disadvantages. Limitations in available techniques to separate autotrophic (root) and soil heterotrophic respiration have hampered the understanding of forest carbon cycling. Autotrophic (root) respiration is here defined as respiration by roots, their associated mycorrhizal fungi and other microorganisms in the rhizosphere directly dependent on labile C compounds leaked from roots.

In this study, subtraction method (Gansert 1994; Högberg *et al.* 2001) is adopted and LI-6400-09 soil respiration chamber (LI-COR Inc., Lincoln, Nebraska, USA) is used to

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measure soil respiration rates with and without roots severed *in situ* in Korean pine (*Pinus koraiensis*) seedlings after four growing seasons exposure to elevated CO_2 in top-open chambers. Therefore, the contribution of roots to total soil respiration is evaluated. This approach overcomes potential concerns about the disturbance of soils, which would otherwise be a significant limitation for the study of natural responses by ecosystems.

Materials and methods

Site description

The study site is situated at the Research Station of Changbai Mountain Forest Ecosystems, Chinese Academy of Sciences (42°24′N, 128°28′E; 738 m in elevation) in the northeast China. The climate of this area is characterized by temperate zone continental climate, with cold and lengthy winters and warm and rainy summers. The mean annual precipitation is about 700 mm, mean annual temperature is about 3.5°C, and the frost-free period is about 100-120 d.

Elevated CO_2 treatments

In 1999, Korean pine was planted in the top-open chambers (OTCs) and in the open field. The soil is dark brown forest soil. Seedlings were treated by high CO_2 concentrations continuously (24 $h \cdot d^{-1}$) during growing season from 1999 to 2003. All plants were irrigated to maintain approximately similar soil moisture. Top-open chamber consists of aluminum frames of 1.2 m in length, 0.9 m in width and height and clear glass covers. The seedlings of Korean pine were treated with three levels of CO_2: 700 $\mu mol \cdot mol^{-1}$ CO_2, 500 $\mu mol \cdot mol^{-1}$ CO_2, control chamber, and open field (ambient CO_2, approximately 350 $\mu mol \cdot mol^{-1}$). Atmospheric CO_2 concentration in each terracosm was monitored continuously using a LCA4 photosynthesis analyzer (ADC, UK) that was calibrated regularly with CO_2 standards. All measurements were made on five-year-old seedlings after they had been exposed to specific treatment for four growing seasons from their emergence. The height of the seedlings is about 30 cm and the density is 60 seedlings per square meter.

Measurement of soil respiration and root respiration

Steel cylinder tubes with 10.5-cm inner-diameter were inserted into the soil about 30 cm in depth (there were almost no roots below this depth) to sever fine roots in each top-open chamber. The steel cylinder was then replaced with PVC (polyvinyl chloride) cylinders with inner diameters and lengths equal to that of the steel cylinder. After one month, soil respirations both inside (soil respiration with roots severed) and outside the cylinders were measured every 3 h during daytime and every 4 h at night from June 15 to 16, 2003 using a LI-6400-09 soil respiration chamber. After four months, soil respiration was measured again on October 8, 2003. The soil chamber is coupled to a LI-6400 photosynthesis system that computes the emissions from the soil to the chamber. Soil temperature at a depth of 5 cm and air temperature were measured concurrently with a temperature probe attached to the photosynthesis analyzer.

Results

Diurnal changes of air and soil temperatures at depth of 5 cm, total and root severed soil respirations

During the soil respiration measurements the diurnal air temperature and soil temperature at depth of 5 cm ranged from 12.88°C to 30.29°C and from 11.19°C to 25.91°C, respectively (Figs.1, 2, 3 and 4). The temperatures increased in the morning and decreased in the afternoon. In general, air temperature was higher than soil temperature at depth of 5 cm. However, they tended to be the same before sunrise. The maximum soil temperature at depth of 5 cm lagged behind that of air temperature. No differences in air temperature and soil temperature were found at depth of 5 cm between treatments.

Both total soil respiration and soil respiration with roots severed showed a strong diurnal pattern, increasing from before sunrise to about 14:00 in the afternoon and then decreased until the next day before sunrise (Figs. 1, 2, 3 and 4). The pattern of soil respiration was similar to that of temperature, which indicated that soil respiration rates were affected by temperature greatly.

The regressions of soil respiration rate and soil temperature at depth of 5 cm indicated that there were significantly logarithmic correlations between them (Table.1).

Table 1. Correlation equations between soil respiration (Rs) rate and soil temperature (Ts) at depth of 5 cm

Soil respiration	Site	Equation	r
Total soil respiration	A	Rs=2.04ln(Ts)-1.72	0.78
	B	Rs=3.81ln(Ts)-7.32	0.82
	C	Rs=1.70ln(Ts)-2.10	0.87
	D	Rs=1.78ln(Ts)-1.89	0.69
Soil respiration with roots severed	A	Rs=1.66ln(Ts)-1.51	0.78
	B	Rs=3.02ln(Ts)-5.45	0.87
	C	Rs=1.82ln(Ts)-2.66	0.91
	D	Rs=1.89ln(Ts)-2.51	0.69

Note: A: the open field; B: control chamber; C: 500 $\mu mol \cdot mol^{-1}$ CO_2 chamber; D: 700$\mu mol \cdot mol^{-1}$ CO_2 chamber.

Effects of elevated CO_2 on total soil respiration rate and contribution of root respiration to the total soil respiration and seasonal variations of them

The values of total soil respiration in the open field, control chamber and elevated CO_2 (500 $\mu mol \cdot mol^{-1}$ CO_2, 700 $\mu mol \cdot mol^{-1}$ CO_2) chambers were 3.96, 3.24, 2.63, 3.19 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively, which is the highest in open field and the lowest in 500 $\mu mol \cdot mol^{-1}$ CO_2 chamber on June 16. However, soil respiration rate in the open field was

lower than that in other chambers on August 20. There was an increase of soil respiration rate with the increase of CO_2 concentration on October 8 (Fig. 5).

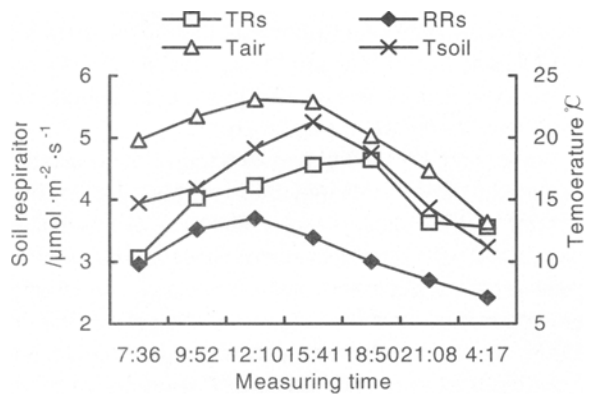

Fig.1 Diurnal variations of total and soil respiration with roots severed, air and soil temperatures at depth of 5 cm in the open field

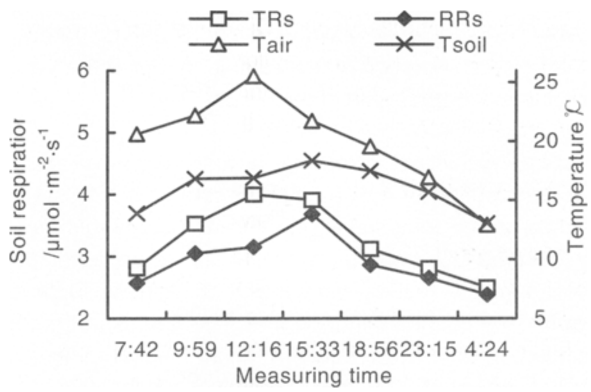

Fig.2 Diurnal variations of total and soil respiration with root severed, air and soil temperatures at depth of 5 cm in control chamber

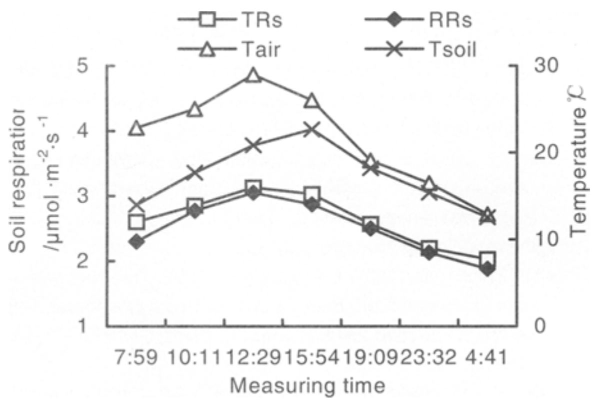

Fig.3 Diurnal variations of total and soil respiration with roots severed, air and soil temperatures at depth of 5 cm in 500 μmol·mol^{-1} CO_2 chamber

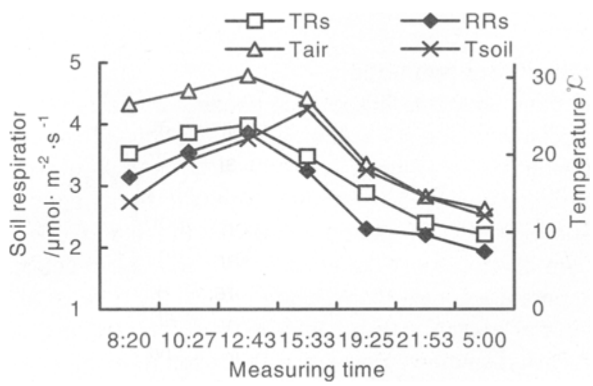

Fig.4 Diurnal variations of total and soil respiration with roots severed, air and soil temperature at depth of 5 cm in 700 μmol·mol^{-1} CO_2 chamber

TRs: Total soil respiration rate; RRs: soil respiration rate with roots severed; Tair: air temperature; Tsoil: soil temperature

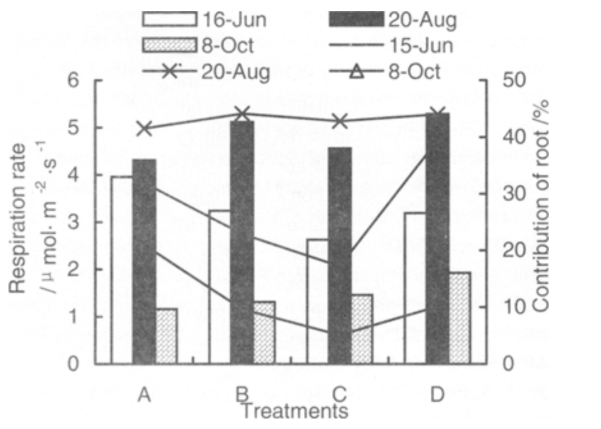

Fig.5 Total soil respiration and contribution under different treatments in different months

Based on the analysis of Fig. 5, it was found that soil respiration rates in different treatments were the highest on August 20 and the lowest on October 8. The contribution of root respiration to the total soil respiration had a similar pattern to soil respiration with the changes of seasons.

Discussion

Effects of elevated CO_2 and contribution of root respiration to the total soil respiration

Elevated CO_2 can increase (Rouhier *et al.* 1996; Janssens *et al.* 1998; Lin *et al.* 1999), decrease (Gifford *et al.* 1985; Callaway *et al.* 1994) or have no effect (Oberbauer *et al.* 1986; den Hertog *et al.* 1993) on soil respiration and contribution of roots. Therefore, it is difficult to draw any definitive conclusions on the effects of elevated CO_2 on respiratory processes. The discrepancy and lack of uni-

formity in specific soil respiration responses to elevated CO_2 could be attributed to a number of factors, including the methods utilized, the concentration of CO_2 at which the measurements were made (Qi *et al.* 1994; Burton *et al.* 1997), the tree species investigated (Lee & Jarvis, 1995), growth conditions, duration of the treatment, age of the tree seedlings, and interpretation of the results.

There was significant difference in total soil respiration and the contribution of root between treatments (P<0.01). No increase in the total soil respiration and contribution of root by elevated CO_2 treatments was observed on June 16. However, opposite results were found on August 20 and October 8. The reasons might be that: The first experiment was conducted about two weeks after the seedlings were exposed to elevated CO_2 concentrations, when elevated CO_2 had not affected them. After the treatments of several months, both soil CO_2 concentration and carbon allocation of seedlings to roots might be increased, which may have caused the increase of soil respiration on August 20 and October 8.

Estimate of root respiration

Field measurements are difficult because roots can not be extracted from the soil without any disturbance (Thierron & Laudelout, 1996; Hanson *et al.* 2000). Most of the direct measurements of root respiration reported in literatures were performed with potted plants in the laboratories (Lambers *et al.* 1991). Furthermore, they may have different temperature sensitivities (Boone *et al.* 1998; Atkin *et al.* 2000; Epron *et al.* 2001) and their relative contributions to the total soil respiration may vary with season (Hanson *et al.* 2000; Epron *et al.* 2001). Estimates of the contribution of root respiration to total soil respiration vary as widely as between 10% and 90% depending upon the type of ecosystem studied and the method used (Hanson *et al.* 2000). Although many attempts have been made to estimate the root contribution to total soil respiration, it is difficult to compare results estimated by different methods because each method has its own limitations (Behara *et al.* 1990). Therefore, our results were compared with the results obtained from similar methods, such as the clear-cutting or girdling method.

In this study, we found that the mean contribution of root to total soil respiration in different treatments were 11.5%, 43.1%, and 27.9% on June 16, August 20, and October 8, respectively (Fig. 5). This was somewhat lower than that calculated in the previous studies (Nakane *et al.* 1996; Ohashi *et al.* 2000; Högberg *et al.* 2001; Bhupinderpal-singh *et al.* 2003). However, the estimate of the contribution of roots respiration to total soil respiration may be conservative. The first experiment was conducted aftre the roots had been severed about one month, when root carbohydrate reserves were probaly mobilized to support root function in the absense of a supply from aboveground. In addition, increased root death may have stimulated grater respiration levels of heterotrophic (decomposer) organisms than those that would naturally occur in forests. Lee *et al.* (2003) found that root respiration is negligible by 3 months after root excision. Therefore, the contribution of root on August 20 was higher than that on June 16. The last experiment was conducted in the end of growing season, when roots activity was small. Thus, the contribution of root was lower than that on August 20.

Comparing the total soil respiration rates *in situ* and soil respiration with roots severed enables us to estimate natural root respiration in the absence of any soil disturbance and with little labor force. However, this method necessitates consideration of the effects of any changes in environmental conditions after severing root. In the present study, the same environmental conditions could be controlled in the top-open chambers. Therefore, we concluded that this approach is one simple and effective method for estimating the contribution of root respiration to total soil respiration.

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